Characterizing Ambiguous Visual information in the Brain through intracranial EEG

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Management Summary

In order to guide our actions, the human brain relies most on the information that is received from the visual sense. However, the visual input the brain receives through the eyes is often subject to noise and ambiguity. Consider for example a person driving a car through the fog. In this situation, the visual information that the brain receives is severely degraded. It is obvious that the brain needs a way to resolve such ambiguities in order to be able to provide the reliable visual information necessary to guide our actions.

The neural mechanisms that are involved in resolving ambiguity in the visual input have been the subject of many studies for over a century. In recent years, many studies have used psychophysics and neuroimaging to investigate how and where the brain processes and resolves ambiguous visual information. In this study we used a structure-from-motion stimulus to investigate the neural responses during the viewing of an ambiguous stimulus.

To investigate these neural responses underlying ambiguous visual perception we used a novel approach. Intracranial electroencephalography is a relatively new method that provides several advantages over more commonly used methods such as scalp EEG or magnetic resonance imaging. The electrodes that are used to record the electrical activity of the brain are implanted directly on the surface of the brain. This allows for more accurate measurements of brain activity because there is no interference from the skull and skin which cause problems in scalp EEG.

Using intracranial EEG, we identified two separate locations in the left hemisphere of one participant that showed a significant difference in alpha band power during a switch in perception when viewing an unambiguous stimulus compared to viewing an ambiguous stimulus. This difference could indicate that the neuronal populations at these locations respond preferentially to bottom-up visual information and not to top-down visual information. A subsequent analysis of the time-frequency spectrum revealed no significant differences but clearly showed a decrease in power in the lower frequencies before the participant responded to a change in the stimulus. This decrease in power is likely related to the preparation of the motor response.

The results of this study show that intracranial EEG is a useful new method that can provide an improvement over scalp EEG.
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1. Introduction

To guide our actions, the human brain mostly relies on the information obtained through visual perception. As numerous multi-sensory illusions show (e.g. McGurk effect (McGurk & MacDonald, 1976), rubber hand illusion (Botvinick & Cohen, 1998)), the information from the visual modality nearly always modifies or even overrides information that is obtained through other sensory modalities. Yet, the input the brain receives from our eyes is nearly always ambiguous and uncertain because of (amongst other things) varying lighting conditions, visual occlusion and high speeds. Therefore, this introduces the question: how does the brain resolve this ambiguity to improve the reliability of the visual information?

Perception is considered ambiguous whenever a single physical stimulus can give rise to multiple perceptual interpretations or 'percepts'. Within the domain of visual perception a well-known example of such a stimulus is the Necker cube (Figure 1). If an observer continuously perceives such a stimulus, perception will alternate between the possible percepts over time in an unpredictable way. Over time, the average percept duration will be approximately the same for each possible percept. The duration of each percept will typically be in the scale of seconds, depending on stimulus parameters (Brouwer & van Ee, 2006; Klink et al., 2008) and other factors such as attention (Meng & Tong, 2004; van Ee et al., 2005).

What happens exactly in the brain when the eyes receive such ambiguous input has been the focus of several studies for a long time. Neuroimaging studies have shown that both extrastriate (Kleinschmidt, 1998; Tong et al., 1998) and striate (Lee et al., 2005) cortex respond to these changes in perception. Furthermore, recent studies also indicate that non-sensory areas such as frontal or parietal cortex could be involved in these perceptual switches (Sterzer et al., 2002; Zaretskaya et al., 2010; de Graaf et al., 2011), possibly related to the frontoparietal attentional network (Naghavi, 2005). Although the precise role of these non-sensory areas is not yet understood, it appears they will most likely be more involved in the voluntary switching of percepts and not in the spontaneous switching that occurs during passive viewing (de Graaf et al., 2011).

In the present study, we used a novel approach to investigate the neural correlates of these switches in perception during the viewing of a bistable structure-from-motion stimulus. Using intracranial electroencephalography (EEG) it is possible to measure brain activity at both a high spatial resolution (in the order of millimeters) and a high temporal resolution (in the order of milliseconds). Such a high spatio-temporal resolution provides clear advantages over more commonly used methods such as magnetic resonance imaging (MRI) and scalp EEG.

Due to the invasive nature of the intracranial recording method, requiring surgical placement of the electrodes, this procedure is currently only allowed in patients who need to be monitored for epileptic seizures. Although this places a limitation on the availability of participants, most patients need to be monitored for a period of two weeks and are typically willing to participate in scientific experiments.

1.1. Objective

The goals of this study are twofold 1) to investigate neural processes underlying visual perception and 2) to develop a method to achieve this using intracranial EEG.

1.2. Problem description

The problem that is addressed in this study is the way the human brain is able to resolve ambigui-
ity in the visual input that is received through the eyes.

1.3. Solution approach

To provide an answer to the question of how the brain resolved such ambiguities, we employed a novel method to study the neural processes that underlie visual perception.

This report follows the general format of a scientific journal publication, i.e. we first describe the methods that were used followed by the results that were obtained using these methods. Finally, the results will be discussed in relation to previous findings in literature.

1.4. Intended audience

The intended audience for this report is the vision science community. However, most concepts will be explained briefly to aid comprehension for non-expert readers.
2. Methods

2.1. Participants

Data was collected from three participants with normal or corrected-to-normal vision. All the participants were patients with pharmaco-resistant epilepsy and were undergoing pre-surgical monitoring to localize the focus of their epileptic seizures.

For all participants, the relevant areas for our study were located at a sufficient distance from the epileptic focus to prevent interference with the epileptic activity.

One of the participants had a tumor (Figure 2) that was unrelated to the epileptic activity. The electrodes that covered this part of the cortex were excluded from the analysis.

All participants gave written consent to participate in the study and the protocol was approved by the local ethics committee of the University Medical Center Utrecht.

2.2. Intracranial recordings

Brain activity was recorded using intracranial electroencephalography. This method entails removing part of the skull and implanting the electrodes directly on the surface of the brain, thereby removing the low pass filtering effect of the cerebro-spinal fluid, skull and scalp (Nunez & Srinivasan, 2006).

Conventional, scalp-recorded EEG suffers from several disadvantages that mostly affect the quality of the recorded signal. Because of the low pass filtering effect the scalp-recorded EEG signal typically can only contain frequencies up to about 100Hz. The coarse coverage of the brain by the electrodes used in scalp-recorded EEG cause the resulting signal to be relatively low in spatial resolution. However, this is not necessarily a disadvantage as some processes are only detectable using this ‘big picture’ approach (Nunez & Srinivasan, 2006).

Another important disadvantage of scalp-recorded EEG are the muscles that lie on top of the

![Figure 2: CT scans of two subjects (CW,JF) overlayed with the electrode locations. Left CT image of the right hemisphere of participant CW. Right Electrode locations of participant JF on left hemisphere. The highlighted blue area (right, participant JF) is a tumor. Electrodes placed over or near this tumor were excluded from the analysis.](image-url)
head. These muscles are controlled by electrical potentials and therefore influence the recorded signal because these signals are much stronger compared to the signal originating from within the skull. This is seen strongest by the muscles that control the movement of the eyes, which can cause large artifacts in the recorded EEG signal.

With intracranial EEG the electrical brain activity is recorded directly on the surface of the brain. This results in a relatively high signal-to-noise ratio (as compared to the scalp recorded EEG) as well as in a high signal amplitude. Furthermore, the spatial localization of the signal is improved as compared to scalp recorded EEG (Freeman et al., 2003). The intracranial EEG signal is also affected to a lesser extent by eye movements and other muscle-related artifacts which adversely affect the scalp-measured EEG.

2.3. Data acquisition

The intracranial EEG data was acquired using respectively 96, 80 and 104 electrodes in the three participants, arranged in grid-configurations of either 8x2, 8x4 or 8x8 electrodes. The conductive surface of each individual electrode was approximately 4mm in diameter and the electrodes were spaced by 1cm center-to-center. Figure 2 shows the placement of the electrodes for two participants superimposed on a CT scan of their brains.

Based on previous studies (Kleinschmidt et al., 1998) the cortical areas that were the focus of this study are the occipital and parietal cortex. Because these recordings are obtained from epileptic patients under observation for seizure activity, the exact placement of the electrode grids was determined based on clinical criteria by a physician. The participants in this study were selected based on the electrode coverage of both occipital and parietal areas.

Preprocessing consisted of filtering the recorded signal with a notch filter at 50Hz, 100Hz and 150Hz to remove line noise and a bandpass filter between 4Hz and 100Hz. All of the epochs were visually inspected for epileptogenic activity and removed if these were present.

The data for participant RV contained too much epileptogenic activity and other noise caused by movement of the participant to be useful for further analysis. For this reason, we only included this participant in the analysis of the behavioral results and not in the EEG analyses.

2.4. Stimuli and task

The participants viewed the stimuli on a CRT computer monitor (resolution: 1024x768, refresh-rate: 85Hz) at a viewing distance of ~100cm. Stimuli were 7cm in diameter which amounted to 4 degrees of visual field. Each stimulus consisted of 300 to 350 dots moving laterally with a sinusoidal speed profile to simulate a flat projection of scattered dots on the surface of a transparent sphere rotating around its vertical axis. Due to the lack of depth information in the stimulus, the direction of rotation of the perceived sphere is not determined by the information received by the

Figure 3: The stimulus used in the experiment (left) consisted of 300-350 dots laterally moving with a sinusoidal speed profile in order to simulate a transparent rotating sphere with ambiguous direction of rotation. The two possible interpretations for the direction of motion (clockwise or counter-clockwise) are shown on the right.
two eyes, but has to be inferred by the brain (Figure 3). The stimuli were presented on a mean luminance gray background.

The experiment consisted of two different stimulus conditions: ambiguous and unambiguous presentation. Each of the two stimulus conditions was presented continuously for 120 seconds per session, with 4 sessions of ambiguous presentation and 4 sessions of unambiguous presentation per participant. Between each session and the following session a neutral stimulus was presented consisting of only the fixation dot and the mean luminance background for 10 seconds.

In the ambiguous presentation, participants continuously observed the stimulus as described above for the entire period of 120 seconds. The task was to indicate the moment where a switch in the perceived direction of rotation occurred by pressing the appropriate button on a two-button response box.

The unambiguous presentation condition was equal to the ambiguous condition, except that participants viewed the display through a pair of anaglyph (red-green) glasses. Using these filters, the perceived direction of rotation could be manipulated by introducing disparity in the displayed stimulus.

The reaction time of the participants to the unambiguously presented stimulus was used to determine the average response time for a participant to report a switch in perceived direction. Across participants, the average reaction time in the unambiguous condition was 1 second (+/- 300ms). In figure 4 the distribution of reaction times for all three participants is shown.

All three participants had a percentage of correct responses to the unambiguous stimulus switches of 95% or higher. This shows that participants were able to maintain attention during the experiment.

2.5. Data analysis

2.5.1. Comparing individual subjects

In the analysis of EEG data, the statistical power of the analysis can often be improved by grouping data from individual participants into a grand average. This is only possible if the electrode location is invariant across participants. In this study, this is not possible because the electrode placement is different for each participant. Therefore, the data in this study is analyzed on a per participant basis.

Establishing basis for comparison across participants, by grouping the signals coming from neighboring electrodes, can be useful to determine the relevance of an effect that is found in the data. Grouping the electrodes in this way reduces the spatial resolution of the recorded data. Yet, the resulting spatial resolution is still higher compared to that scalp recorded EEG.

Here, the electrodes are grouped by location in relation to the cortical area they cover and analyzed within each area. The analysis is limited to the electrodes that cover the cortical areas that are of interest for the current study, i.e. the parietal and occipital cortex.

2.5.2. Epoch selection

Instead of analyzing the entire recorded EEG signal, the signal is divided into smaller segments, epochs, which are aligned around a particular event or feature of the signal. In this study we were interested in the modulations of the recorded signal around the switch in perceived direction of rotation. Since the exact time of the perceptual switch is unknown in the ambiguous presentation condition, the button press is used as a reference to segment epochs in the data.

From the responses to the unambiguous stimulus, the average reaction time to these perceptual switches was computed and this was found to be 1 second on average. To ensure that the actual perceptual switch would be included in the epoch, a window of 3 seconds (from -2 to +1 seconds) was selected around each button-press event.
Because neuronal activity is an ongoing phenomenon, a common procedure in EEG analysis is the determine a baseline level of activity, i.e. activity that can be regarded as unrelated to the experimental manipulation. This baseline should ideally only contain noise related to the features of the stimulus that are not of interest to the studied effect. For this analysis, the baseline for every epoch was taken from -3 seconds to -2 seconds before the response.

### 2.5.3. Frequency bands

A well-known property of neuronal activity is that specific types of neuronal oscillations can be related to stimulus processing. This relationship between an external stimulus and oscillations in the brain are mostly characterized by the type of information that is processed and the range of frequencies at which this happens.

An example of this correlation are the neural oscillations that can be measured over occipital sites when a person closes her/his eyes. Whenever the person closes her/his eyes, the power in the frequency range of 8-12Hz (known as the alpha band) increases. This is more pronounced in occipital sites. When the eyes are opened again, the alpha power decreases (Pfurtscheller et al., 1996). Similar correlations exist between muscle activity and the power in the frequency range from 12 to 25Hz (beta band).

To investigate the effect of the perceptual switches on the neural activity, the data was filtered at two frequency bands: 4Hz to 8Hz (theta band) and 8Hz to 12Hz (alpha). The filtering was done using a zero-phase Finite Impulse Response (FIR) filter to avoid phase distortions introduced by the filter.

### 2.5.4. Event-related power

Given that the phenomenon of interest occurs at a specific point in time, event-related power changes (ERP) around the time of the perceptual switch were analyzed. An event-related power change is an increase or decrease in the power of the recorded signal that is time-locked to a specific external or internal event.

To compute the event-related changes in power for each electrode, the recorded signal was first filtered at one of the two frequencies as described above. Subsequently the recorded signal was converted to instantaneous power by averaging the squared signal samples over a 150 ms-long window. Finally the signal was compared to the baseline level to produce the event-related changes.

Channels that were grouped in the same cortical regions (see section 2.5.1) were averaged together to produce an average ERP for every area in each participant.

### 2.5.5. Spectral analysis

To provide a more detailed analysis of the spectral content of the signal over time, the recorded EEG signal was decomposed into a time-frequency spectrum using a continuous wavelet transform (CWT). The continuous wavelet transform of an analog signal \( f(t) \) is expressed as:

\[
C(b, a) = \left| a \right|^{\frac{1}{2}} \int_{-\infty}^{\infty} f(t) \psi^* \left( \frac{t - b}{a} \right) dt
\]

(1)

The function \( \psi^* \left( \frac{t - b}{a} \right) \) is obtained by translation \( b \) and dilation \( a \) of the “mother wavelet” \( \psi(t) \). The end result of the CWT is a set of wavelet coefficients \( C(b, a) \), one coefficient for each point in the time-frequency spectrum.

In this analysis the signal was decomposed into its time-frequency spectrum using a seven-cycle
Morlet wavelet as basis function (or “mother wavelet”) over a range of frequencies from 4Hz to 100Hz and a time window between 2 seconds before and 1 second after the subjects’ response to the perceptual switch.

2.5.6. Statistical test

To assess the difference between the recorded signals in each of the two conditions, ambiguous and unambiguous presentation, a Student’s t-test was used. This method is commonly used to quantitatively assess the difference between two populations of data and to determine whether this difference is statistically significant or not. Because we are using measurements from multiple sites (electrodes), multiple time points and multiple frequencies, the statistical tests were corrected for multiple comparisons. Because the electrode channels cannot be assumed to be completely independent from each other, a cluster-based method (Monte Carlo) was used.
3. Results

3.1. Behavioral data

The analysis presented here depends on the subjects’ response to the perceived switch in direction of rotation. In figure 5 the time courses of the perceptual switches for the three participants are presented. Each bar represents the time course for an individual participant and each segment within a bar represents a period of perceptual stabilization (white for clockwise and black for counterclockwise rotation). In agreement with previous research (Aafjes et al., 1966; Kanai et al., 2010) the three participants show a large inter-individual variability in the number of perceptual switches as well as in the average duration of a period of stabilized perception.

Subjects CW, JF and RV had a total of 33, 47 and 52 reversals, respectively, with a mean duration of the stabilized period of 13 seconds, 9 seconds and 7.5 seconds. As described previously, the subjects were able to perform the task and attend to the stimulus as indicated by the percentage correct responses to the unambiguous viewing conditions (>95% for all subjects, Figure 4).

3.2. Event-related power changes

To identify and investigate processes dedicated to resolving the ambiguity in the stimulus, we looked at the difference between the recorded signals at the moment of the perception switches in the ambiguous and unambiguous situations.

The results of this analysis in the occipital and parietal areas are shown for subjects CW and CJ in Figure 6 and Figure 7 respectively. The two lines in each plot show the averaged ERPC during each of the two conditions: ambiguous (red) and unambiguous (blue). The light and dark gray bars indicate the standard deviation for the ambiguous and unambiguous viewing conditions. On the y-axis the instantaneous power (µV²) is plotted and the x-axis shows time, ranging from 0 to 2 seconds.

Figure 4: Distribution of response times for three participants in the unambiguous presentation condition. Average reaction time was 1 second +/- 300ms.
from 2 seconds before subjects’ response (0 = response) to 1 second after the response. These figures show the event-related power changes during the selected time window, averaged over epochs. The results are also averaged over electrodes within a cortical area (i.e. parietal or occipital). The figures presented here are representative of the underlying individual electrodes.

**Figure 6**: Event-related power for the occipital electrodes of subjects CW (top row) and JF (bottom row). The plots in the left column show the theta band ERPC for each participant and the right column shows the alpha band results.

**Figure 7**: Event-related power for the parietal electrodes of subjects CW (top row) and JF (bottom row). The plots in the left column show the theta band ERPC for each participant and the right column shows the alpha band results.
Figure 6 shows the average event-related potential for both subjects over the occipital cortex in the theta (left column) and alpha (right column) bands. In both subjects and both frequency bands, the results show no significant difference between the two presentation conditions at any time point within the selected temporal window. There appears to be a small peak in the theta band for participant JF (left, bottom) just before the response to the stimulus. However, this peak is not significant (p > 0.7) and also not consistent over epochs.

Figure 7 shows the results of the ERPC analysis for the electrodes that are located over the parietal cortex in both subjects. Both the theta (left column) and alpha (right column) bands do not show any significant difference between the ambiguous and unambiguous condition, neither around the time of the perceptual switch nor around the time of the button press.

Although these figures only show the averaged results for electrodes within cortical areas, these figures are representative of the individual electrodes.

Interesting to note is that the data for participant JF (bottom row in both figures) shows a peak in the alpha frequency band (bottom, right plot) around 1 second before the response to the perceptual switch. This peak is visible in both the occipital and parietal data, although with a small difference in latency, but only in the unambiguous viewing condition (blue line). However, this effect was not significant (p > 0.9) for the whole occipital or parietal cortex (i.e. across all channels).

Subsequent analysis of the individual electrodes revealed two electrodes that did show a significant peak. Figure 8 shows the event-related potentials for two channels located in the occipital (left plot) and parietal (right plot) cortex. These electrodes show the same peak at the same latencies as the whole-area figures 6 & 7. In both electrodes the peak represents a significant difference (p < 0.05) between the unambiguous and ambiguous viewing conditions.

### 3.3. Time-frequency domain

For a more detailed analysis of the spectral changes over time, the measured signal was analyzed into a time-frequency representation. In figures 9 and 10 these representations are shown for participants CW and JF, respectively. Time is reported along the x-axis, frequency is reported along the y-axis, and the spectral power is encoded in a colormap (z-axis). The frequencies (y-axis) range from 4Hz to 100Hz and the time window (x-axis) ranges from 2 seconds before the participant's response (0 = response) to 1 second after the response.

![Figure 8: Event-related power for two electrodes located in the occipital (left) and parietal cortex (right). A significant peak (p < 0.05) in the unambiguous viewing condition (blue line) compared to the ambiguous viewing condition (red line). This occurs around 1 second before the participant's response to the perceptual switch in the occipital cortex (left plot) and between 500ms and 1 second before the participants response in the parietal cortex (right plot).](image-url)
Because the measured signal in individuals differ greatly in the baseline magnitude, the time-frequency data has been normalized into relative power changes (relative to the baseline). This allows for more straightforward comparison between the time-frequency spectra of the two participants. Figure 9 shows the time-frequency spectra for participant CW over both the occipital (top row) and parietal (bottom row) cortex. The figures on the left column show the time-frequency spectra for the unambiguous condition and the figures on the right column show the time-frequency spectra of the ambiguous condition. Figure 10 has been arranged in similar manner showing the data for participant JF.

In the time-frequency spectra recorded over the occipital cortex (top row) of both participants, a decrease (green) in the time-frequency power is visible in the lower frequencies (<20Hz) between 500ms and 0ms before the participants response to the perceived change in the stimulus. This decrease in power is visible in both the ambiguous and unambiguous viewing conditions, and for participant JF this decrease can also be observed in the time-frequency spectra of the parietal electrodes (bottom row). The time-frequency spectra did not show any significant differences in power between the ambiguous and unambiguous viewing condition for participant CW or participant JF.
Figure 9: Time-frequency spectra for unambiguous (left) and ambiguous (right) presentation conditions in participant CW. The top row figures present the data of the occipital electrodes, while the bottom row shows the parietal data. The time-frequency power is normalized relative to the baseline in order to allow for straightforward comparison between the two conditions. Although there seem to be slight differences between the two signals, these differences are not significant ($p > 0.4$).
Figure 10: Time-frequency spectra for unambiguous (left) and ambiguous (right) presentation conditions in participant JF. The top row figures present the data of the occipital electrodes, while the bottom row shows the parietal data. The time-frequency power is normalized relative to the baseline in order to allow for straightforward comparison between the two conditions. Similar to the data of participant CW, there are differences but without statistical significance ($p > 0.5$).
4. Discussion

In this study, we focused on the phenomenon of ambiguous perception by analyzing intracranial brain signal recordings. The benefits of using intracranial electroencephalography over scalp recorded EEG were already validated in several domains such as research on working memory (Meltzer et al, 2008) and brain-computer interfaces (van Steensel et al, 2010).

We have analyzed the dynamics in two specific frequency bands of brain activity known to characterize visual processing: the theta (4-8Hz) and alpha band (8-12Hz). The purpose of this analysis was to identify differences between the measured activity during a perceived change in the ambiguous stimulus and the measured activity during a change in the unambiguous stimulus. Such a difference would indicate the presence of neural processes specific to the perception of the ambiguous stimulus. These processes could then possibly be involved in resolving the ambiguity in the stimulus that allows the visual system to determine what we will see at any given point in time.

Similar to previous literature (Aafjes et al., 1966; Kanai et al., 2010), we have found inter-individual differences in both the frequency of perceptual switches and the duration of periods of stabilized perception. Along with the high percentage of correct responses during the unambiguous presentation condition, this indicates that the participants were able to attend to the stimuli and perform the task.

The recorded synaptic potentials were analyzed separately in each participant and in two cortical areas within each participant. Both participants had electrodes covering the occipital and parietal cortices. However the electrode arrangement was different for each participant.

A third patient had coverage of the parietal cortex, but the recorded data was not sufficiently reliable to be included in the analysis. This patient’s data has been however included in the behavioral results.

In the analysis of the event-related power changes in alpha band (8-12Hz) power for participant JF we found a significant difference between the ambiguous and unambiguous viewing conditions in two electrodes located in the occipital and parietal cortex. This peak in alpha band power was located around 1 second before the participant responded to the perceived change in direction of rotation in the occipital electrode. For the parietal electrode this difference occurred between 1 second and 500ms before the participant’s response.

The alpha band is known to be highly responsive to changes in the visual input that is received through the eyes. Thus, the most likely interpretation of the observed peak in alpha band activity, indicating an increase in synchronization of the underlying neural population, is that it reflects the neuronal response to the change in direction of rotation in the stimulus. This interpretation is also supported by the behavioral data that showed that the average reaction time in the unambiguous epochs was 1 second. Furthermore, this would also explain the shift in latency between the observed occipital and the parietal peaks because it would take more time for this information to reach the parietal cortex (which is located further away in the visual processing flow).

The difference between the recorded EEG signal at these locations is interesting because it suggests that the neural populations at the recording sites are preferentially responsive to the bottom-up information that is present in the unambiguous stimulus and not to the top-down information that is present in the ambiguous stimulus. An alternative explanation could be that because the switch in perceived direction of rotation in the ambiguous viewing condition is not driven by low-level visual input, the neuronal populations at these locations are not driven strongly enough to exceed the baseline level of activity. This explanation would be further supported by the fact that in the ambiguous data the peak is completely absent and not just significantly lower compared to the unambiguous data.

The subsequent analysis of the time-frequency spectrum for both participants revealed no significant differences between the ambiguous and unambiguous viewing condition. In both viewing conditions, the time-frequency spectra showed a decrease in time-frequency power in the lower
frequencies (below 20Hz) between 500ms and 0ms before the participants response to a perceived change in the direction of rotation of the stimulus. Since this decrease occurs in both viewing conditions and in the occipital electrodes for participant CW and both occipital and parietal electrodes for participant JF, the effect is most likely related to the motor response to the perceived change in the stimulus.
3 Conclusions and research agenda

In this study intracranial encephalography has been demonstrated to be a viable method to study the neural processes underlying visual perception in the human brain. Intracranial EEG provides an improvement over scalp-recorded EEG in terms of spatial resolution and the signal-to-noise ratio. These improvements provide an advantage when this technique is used to study the neural basis of visual perception and can complement the use of scalp-recorded EEG.

The main focus of this study was on the neural processes that are involved in resolving ambiguous visual information. In the analysis the results did not reveal any specific locations for these processes in the two participants that were analyzed. The analysis did however reveal two specific sites, in the occipital and parietal cortex that appear to be driven specifically by low-level visual information and not by high-order information present in the ambiguous structure-from-motion stimulus. These results show that the method used to analyze the data was sensitive enough to detect such differences between the recorded EEG signal in the two stimulus conditions.

A possible further direction for the analysis of this data could be the investigation of the higher frequency bands, most notably the gamma (>30Hz) band. The dynamics of the gamma frequency band are typically associated with processing of higher-level stimulus features as well as binding of different low-level stimulus features into a coherent percept. It would be interesting to see if the locations that were found to respond specifically to the low-level features of the stimulus in the theta and alpha frequency bands would also show a response to the higher-level features of the stimulus in the gamma frequency band.

The larger frequency spectrum that is available for the analysis in the data would also provide an opportunity to investigate possible cross-frequency coupling effects that could reflect an interaction between the low-level features of the stimulus and the higher-level features of the stimulus which together lead to the coherent percept.

4 Acknowledgements

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References


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